BRL MR 2001

BRL

AD

MEMORANDUM REPORT NO. 2001

BRL DUAL SHOCK TUBE FACILITY

by

Brian P. Bertrand

August 1969

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2001

AUGUST 1969

BRL DUAL SHOCK TUBE FACILITY

Brian P. Bertrand

Terminal Ballistics Laboratory

Work conducted under OCE-AMC
Letter of Agreement dated 28 April 1967

ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2001

BPBertrand/lse
Aberdeen Proving Ground, Md.
August 1969

BRL DUAL SHOCK TUBE FACILITY

ABSTRACT

The Dual Shock Tube Facility was constructed for use in evaluating the performance of large engine-generator sets operating in a shock wave environment such as would occur during a nuclear attack. The design and operation of the Facility are described and results of shock tube operation are presented.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

A. Background

The Dual Shock Tube Facility (Figure 1) was constructed at Aberdeen Proving Ground primarily for use in evaluating the performance of large engine-generator sets operating in an air shock wave environment. These sets are typical of those that would be deployed in an anti-ballistic missile system. The system would have to operate during an attack so it is important to know what happens to the output power quality during the transient shock loading of the engine's inlet and exhaust. The Office of Chief of Engineers has responsibility for design and construction of power systems within the Army so they initiated the construction of the facility.

B. Simulation Using Shock Tubes

Shock tubes were selected for this evaluation because of shortcomings of the other two alternatives, explosives and underground nuclear tests. The underground nuclear tests are expensive and explosives produce short duration waves. Shock tubes are capable of producing long duration shock waves in a well-controlled, relatively inexpensive manner.

The shock tubes are used to shock load the intake and exhaust of the engine as shown in Figure 2. The engine is placed between the two parallel shock tubes, and the intake and exhaust are connected to the driven sections of the shock tubes by ducting. The engine draws its intake air through the open end of one shock tube and exhausts the combustion products out through the open end of the other tube. Air is pumped into the driver sections to the desired driver pressure and the diaphragms are then burst. Part of the shock waves produced enter the intake and exhaust ducting, travel

Figure 1. Dual Shock Tube Facility

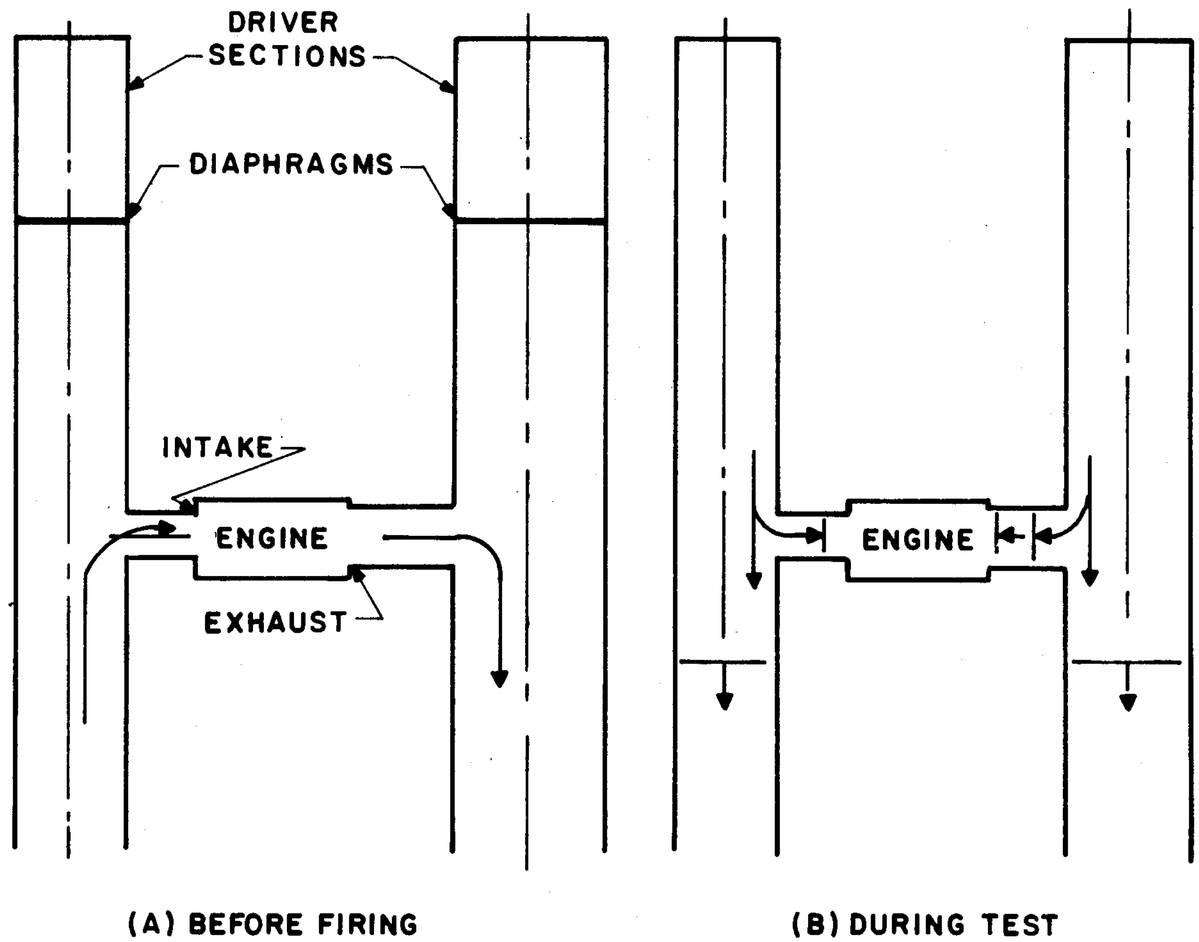


Figure 2. Shock Tube Loading of Engine

to the engine where they reflect and load the engine as desired.

II. DESCRIPTION OF THE FACILITY

A. Shock Tubes

There are two shock tubes whose dimensions are shown in Figure 3 and in Table 1. The distance between the tubes was determined by the length of ducting required to reduce entrance effects to an acceptable level in the ducts. The tube lengths were determined by the desire to obtain long shock waves of equal duration. The intake tube is longer because its heated driver air results in a faster rarefaction wave than in the larger tubes' unheated driver section so the wave duration tends to be proportionately shorter. The diameters were chosen to minimize intake and exhaust flow velocity for the largest engine for which testing is considered; the exhaust tube diameter is larger because of the higher mass flow in the engine exhaust than in the intake air.

1. Small Shock Tube. The smaller (5 1/2 foot diameter) tube is used to load the engine inlet. The short inlet-ducting junction is attached to the tube wall at 60° to the shock tube axis (Figure 4A). A blind flange can be attached to the end of the inlet junction so the tube can be operated singly. During engine testing the ducting to the engine inlet is attached to this junction flange.

The driver wall of this tube is insulated and may be heated to as much as 500° F. This in turn heats the compressed driver air so as to provide a matched interface in the air following the shock front. This eliminates the cold air that would otherwise follow the shocked air and produce unrealistic effects when it entered the engine inlet.

2. Large Shock Tube. The larger tube (8 foot diameter) is driven by unheated compressed air, there being no need to match the interface in this tube because the exhaust gas flow prevents the entry

Table I. Physical Dimensions and Operating Limits

Tube Diameter	Driver Pressure	Driver Temperature	Driver Length	Driven Length	Wall Thickness	Duct Junction Location	Tube Wall Material
5 1/2 ft.	160 psi	500°F	350 ft.	260 ft.	7/16"	73.6 ft. fm diaph.	ASTM A516 gr. 70
8 ft.	160 psi	unheated	270 ft.	230 ft.	5/8"	68.7 ft. fm diaph.	

5 1/2 ft. Dia. Tube

Port No.	Distance (ft.)
51	45.75
52	61.6
52A	61.6
53	63.1
53A	63.1
54	64.6
54A	64.6
55	114.45
56	164.5

8 ft. Dia. Tube

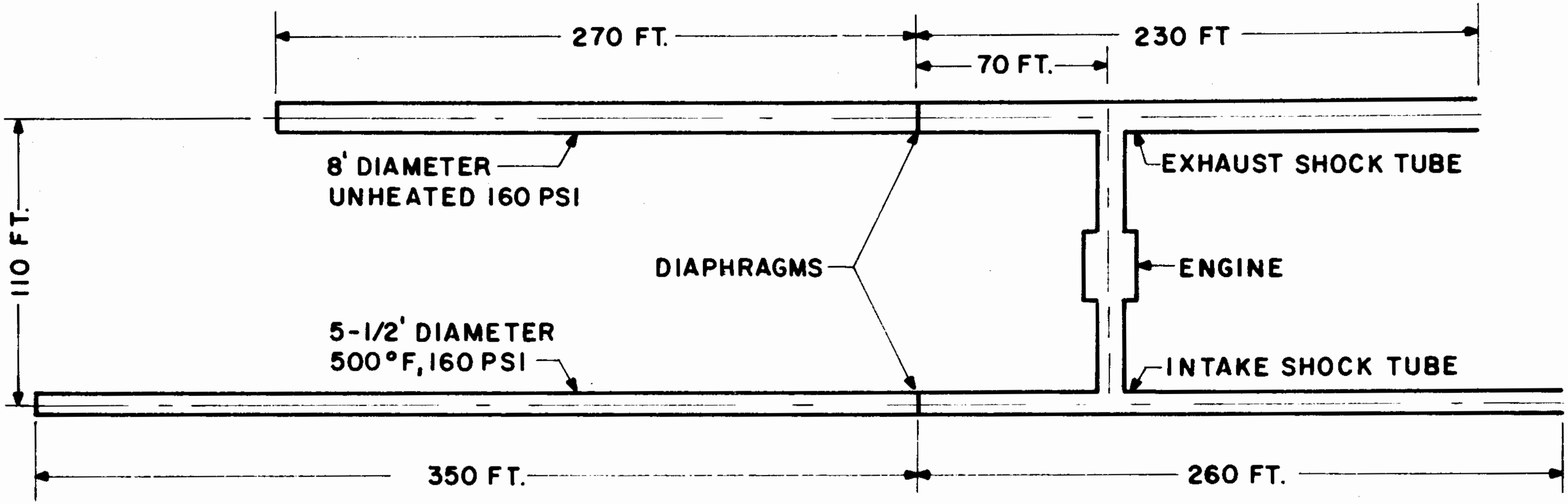
Port No.	Distance (ft.)
81	41.7
82	58.5
82A	58.5
83	62.2
83A	62.2
84	63.7
84A	63.7
85	65.2
86	116.3
87	158.8
88	204.5

Diaphragm Material

1010 - 1015 Steel, hot rolled, as rolled

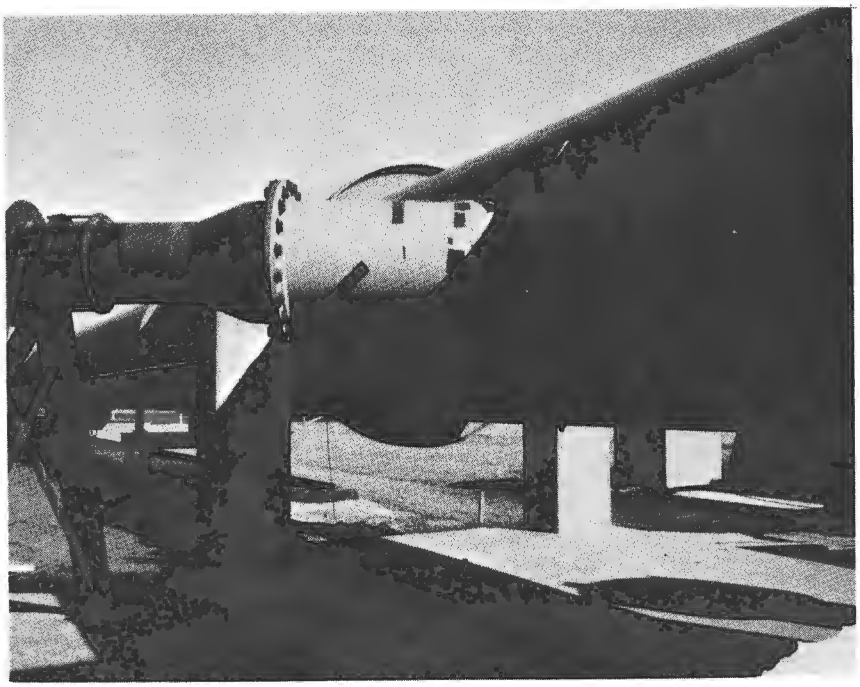
Cutting Charges (RDX Core/Lead Sheath)

Diaphragm Thickness	Core Load
16 gage (0.0598")	20 gr./ft.
14 gage (0.0747")	30 "
12 gage (0.1046")	50 "
10 gage (0.1345")	65 "

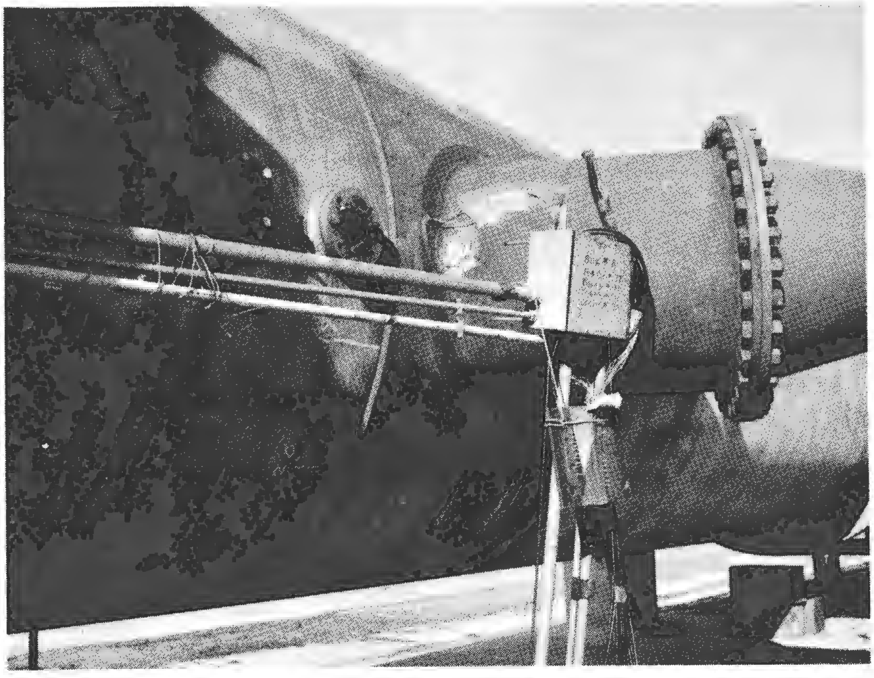


MATERIAL: STEEL (ASTM A516, GRADE 70)
WALL THICKNESS: 8' DIA. – 5/8"
5-1/2' DIA. – 7/16"

Figure 3. Dimensions of Shock Tubes



(A) INTAKE JUNCTION, 5-1/2 FT. DIA. SHOCK TUBE



(B) EXAUST JUNCTION, 8 FT. DIA. SHOCK TUBE

Figure 4. Intake and Exhaust Duct Junctions

of air into the engine exhaust. There is a short exhaust-ducting junction attached to the shock tube wall at 60° to the tube axis (Figure 4B). The end of this junction also can be closed with a blind flange so the tube can be operated singly.

3. Diaphragms. The diaphragms, Figure 5, constructed of steel sheet are mounted on clamping rings, Figure 6. A retaining ring, welded to the perimeter of the diaphragm, fits over a shoulder on the clamping ring. The clamping ring-diaphragm combination is then mounted on the diaphragm section flange, Figure 7A, and this section is then rolled into place in the shock tube, Figure 7B. The diaphragm-clamping ring assembly is then clamped securely between the flanges by tightening the flange bolts, Figure 7C. This is done using air-driven impact wrenches, followed by an accurate check with torque wrenches. The combination of the clamping force exerted by the flanges, and the retaining ring over the shoulder of the clamping ring, prevents the diaphragm from pulling in from between the flange faces when the diaphragm bulges out under pressure. A slip section is then extended to seal off the access space in the shock tube. Figure 7D.

Diaphragm thicknesses are selected that keep the diaphragm material strain below 2/3 the natural burst level. The diaphragm is ruptured by detonating flexible linear shaped charges that are taped along four diagonals, Figure 8, the detonation being initiated at the center of the diaphragm where the charges meet. This produces eight pie-shaped petals that are forced open by the driver air pressure, but are retained and bend along the inside edge of the flange. The petals slap against the inner wall of the diaphragm section and the inertia of each petal tip causes it to wrap around a sturdy bar that is placed over a pocket in the wall, see Figure 9. This tip holds

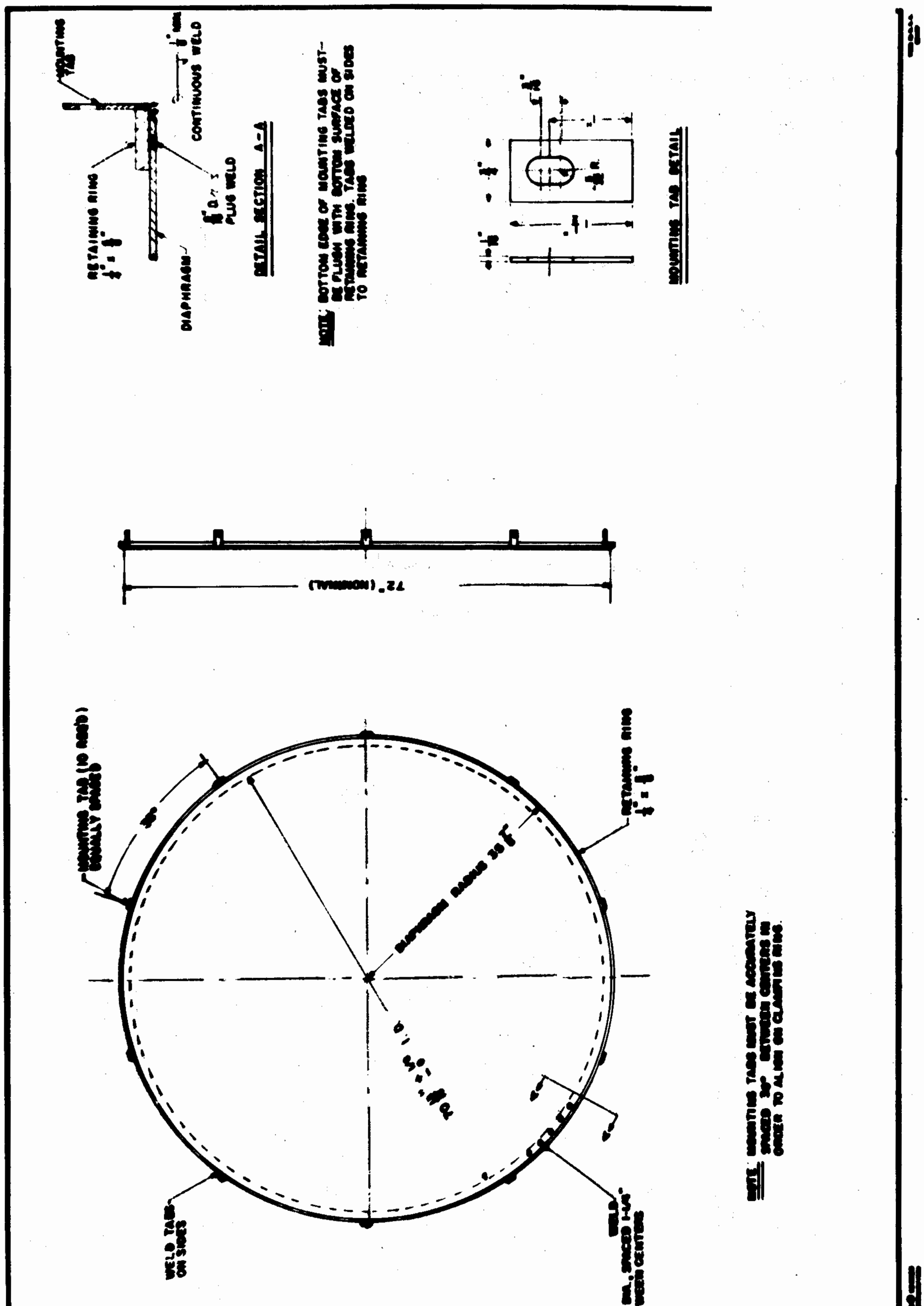


Figure 5. Diaphragm Design

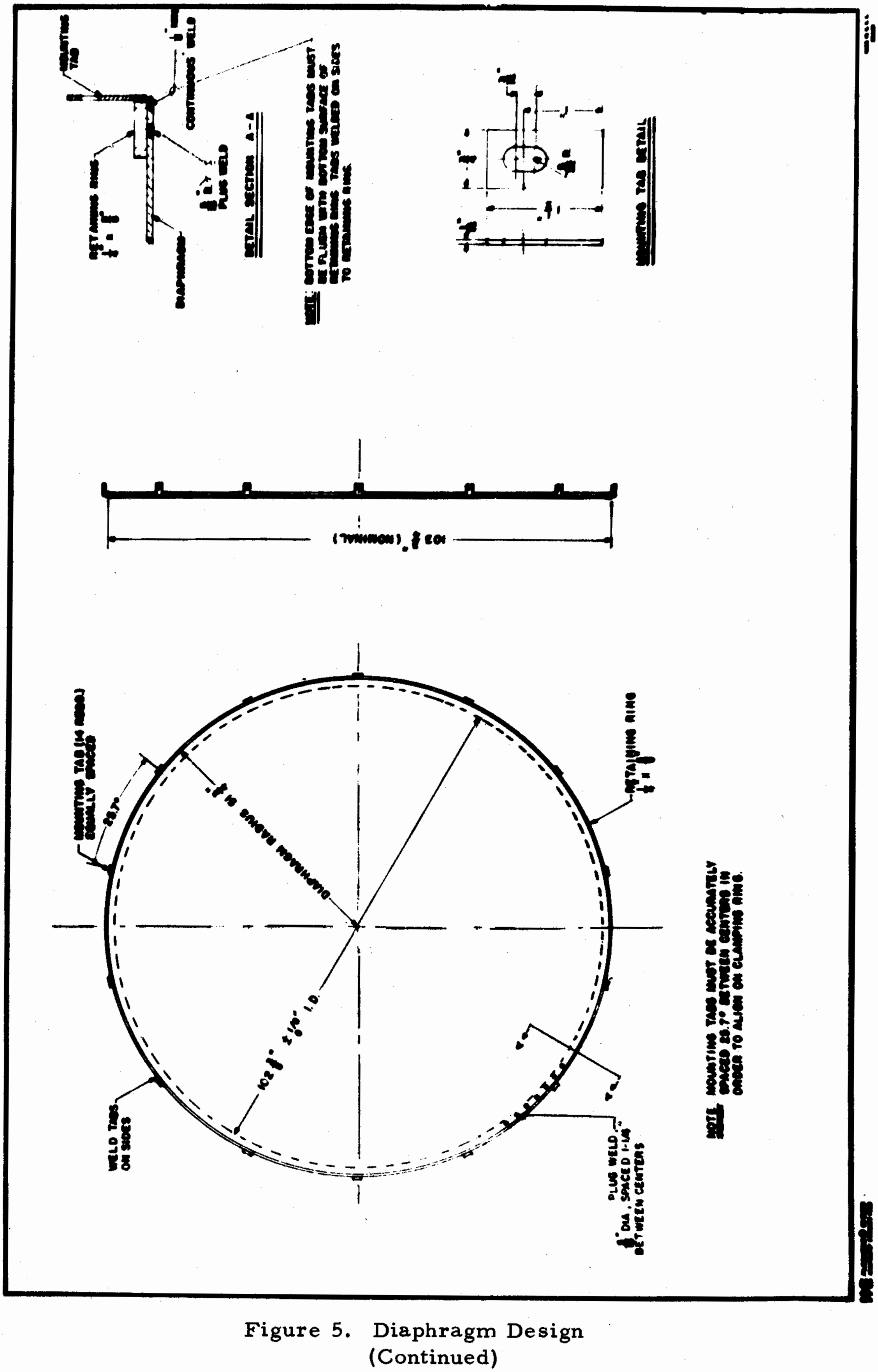
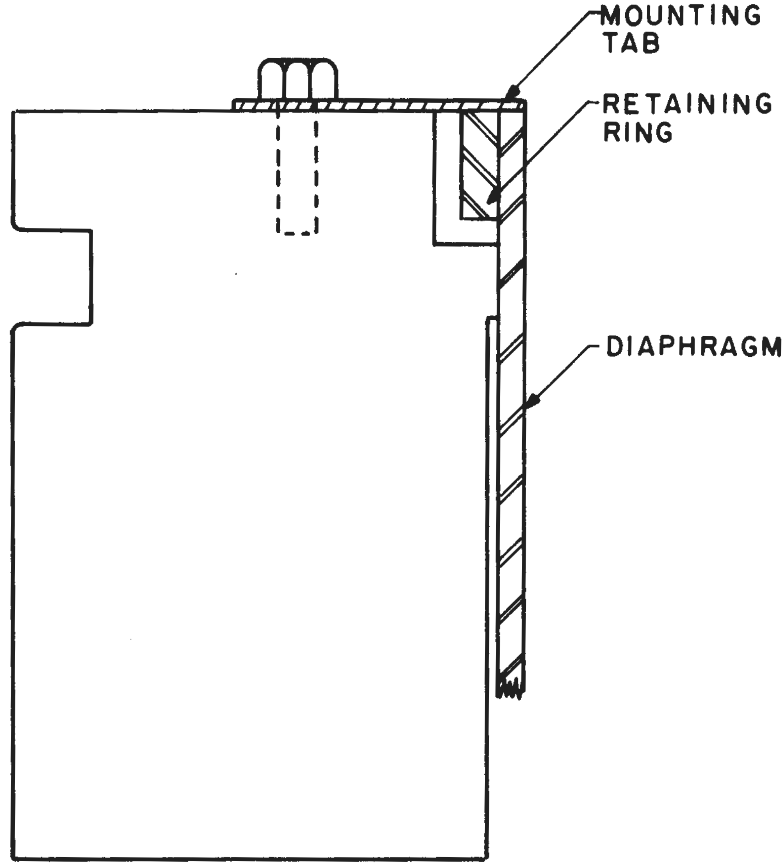
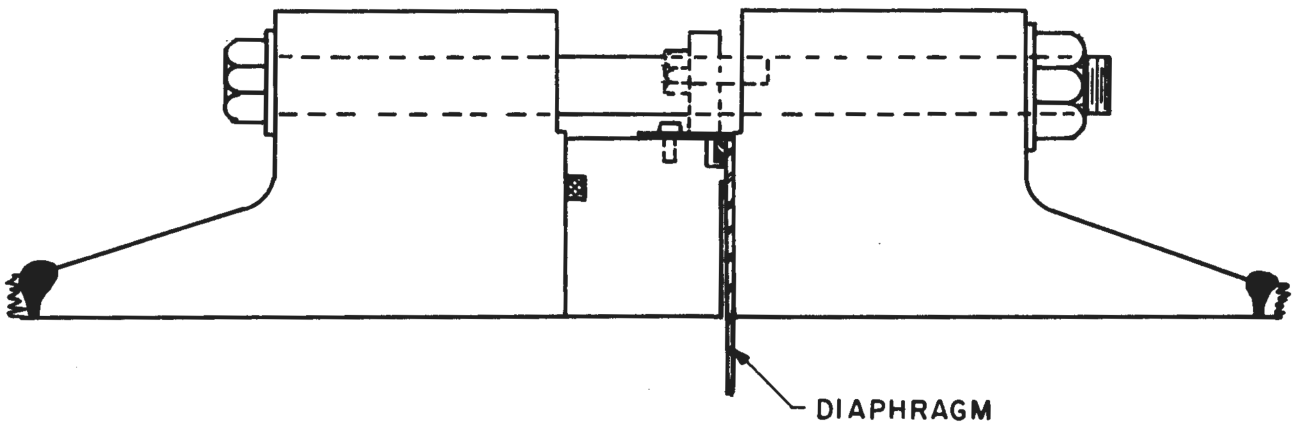


Figure 5. Diaphragm Design
(Continued)



CLAMPING RING



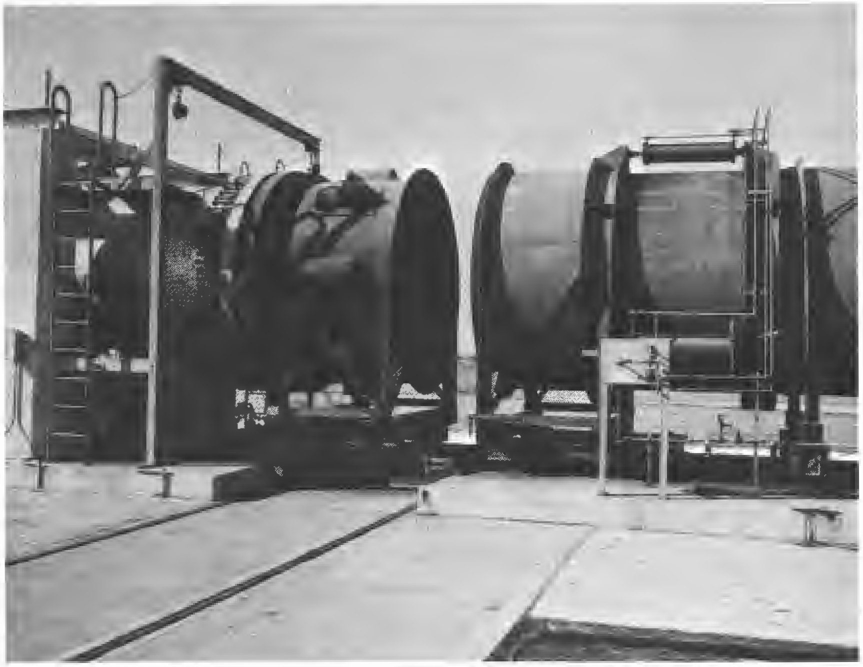
FLANGE CONNECTION

Figure 6. Diaphragm Mounting

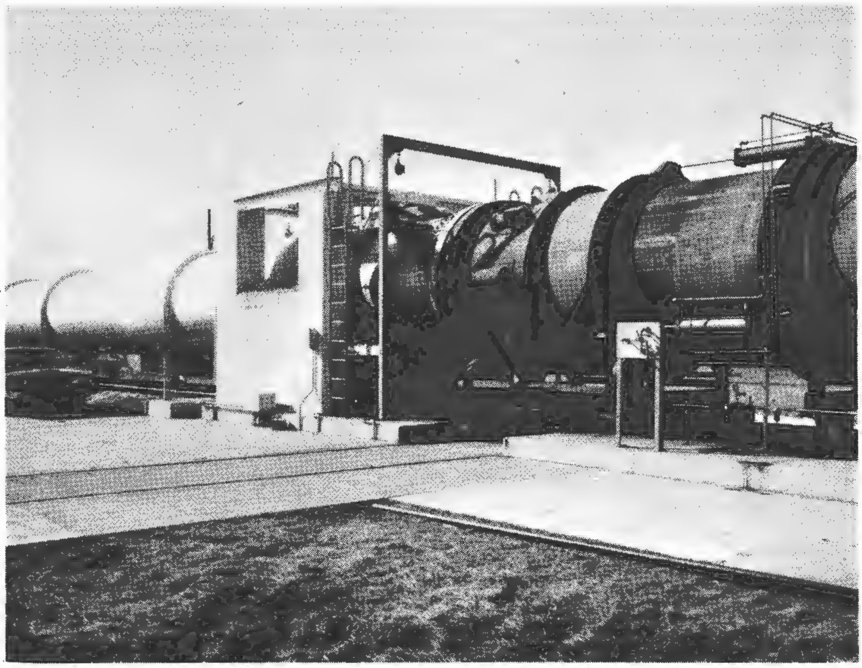
(A)

(B)

Figure 7. Diaphragm Section Emplacement Sequence



(C)



(D)

Figure 7. Diaphragm Section Emplacement Sequence (Continued)

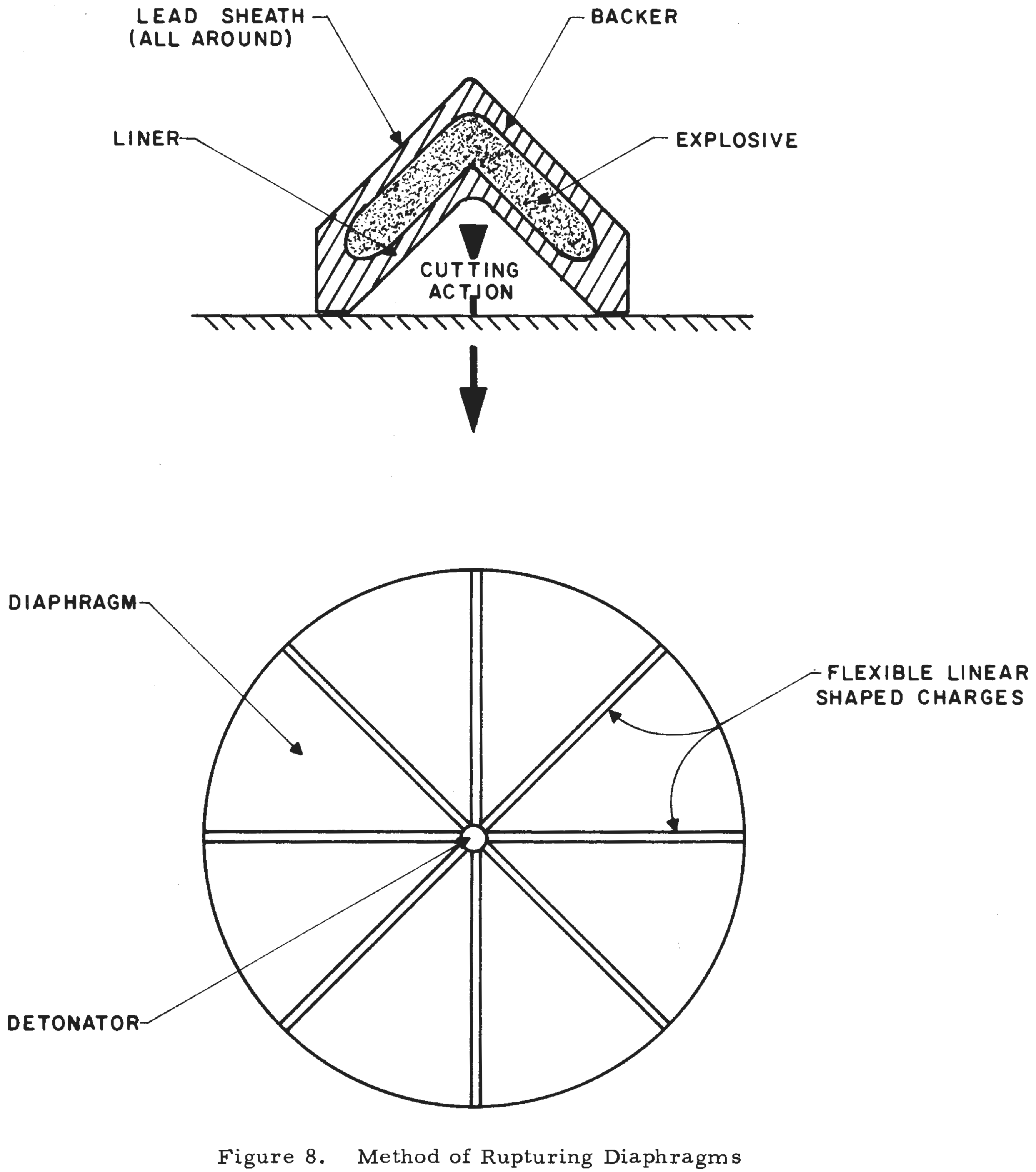


Figure 8. Method of Rupturing Diaphragms

Figure 9. Ruptured Diaphragm

and prevents the petal from flapping back and forth in the flow cycles that occur after the shock, thus reducing the probability of its tearing off.

The diaphragms are pre-bulged in place in the shock tubes before the cutting charges are attached. This prevents the charge from pulling away from the detonator as the diaphragm bulges under pressure. The charges are taped to the downstream face of the diaphragm to eliminate the necessity of unbolting the diaphragm after prebulge and then having to bolt up again.

4. Reaction Foundation. The unbalanced force produced by the sudden opening of the diaphragm acts as an axial thrust upstream on the shock tube. The maximum thrust is about 1.2 million pounds force in the large tube and 550,000 pounds in the small tube at the design driver pressure of 160 psig. This thrust is opposed by a deep concrete reaction foundation to which the driver section is fixed. The bearing properties of the earth surrounding the foundation is kept consistent by a sub-drain system.

5. Instrumentation Ports. Several ports are provided for instrumentation in each tube; their locations are shown in Table 1. The basic arrangement is a 4 1/8 inch diameter hole in the tube wall covered by a 4 inch, 300 pound class flange modified so that it need not be removed to change instrumentation.

B. Buildings and Auxiliary Equipment

1. Control Building. This structure houses the control panel and the recording instrumentation and is also used for shelter when operating the tubes. The walls and roof are constructed of reinforced concrete, 12 inches and 8 inches respectively, for protection in the unlikely event of a failure of the shock tube or the engine under test.

There are no windows in the building so a two channel, closed circuit television is used to assure a safe condition outside the building during tests.

The control panel has the following items for remote operation and indication:

a. Pressure gages for both tubes' driver pressure
b. Pressure recorders both tubes' driver pressure
c. Compressor shut-down switches
d. Driver exhaust control switches
e. Barometer
f. Driven section pressure gages for both tubes
g. Temperature recorder for ambient tube temperatures
h. Clock
i. Tube sequence selector switch
j. Delay generator for time delay between tube firings
k. Firing switch
l. Indicator lights
m. Several minor functions

Recording instrumentation for shock waves use as their input the signals from transducers in the shock tubes. Piezoelectric pressure transducers are used with oscilloscopes for fast response-pressure recording and with electronic counters for shock velocity measurement. When the complete wave must be recorded, strain-type pressure transducers are used in conjunction with galvanometer recorders.

2. Diaphragm and Compressor Building. This building provides space and facilities for attaching new diaphragms to the diaphragm sections, removing spent diaphragms, for storing the diaphragm

supply and tools. A 1-ton bridge crane is used for handling the diaphragms and clamping rings, and for positioning them for attachment to the diaphragm sections. There is a spare set of diaphragm sections stored here also. A set of tracks, extending through the building,allows the diaphragm sections to be moved on their carriages into position at the shock tubes.

Attached to the diaphragm change bay is a room for the compressors, the main power panel and the motor control panel. There are two-100 horsepower 175 psig, 304 scfm compressors used for compressing air in the shock tube driver sections. There is also a 20 horsepower, 250 psig service air compressor for activating the slip sections, remote-controlled valves and impact wrenches, for supplying water pressure and shop air, and for starting the test engines.

III. OPERATION OF THE FACILITY

Driver pressures and temperature are selected from Figures 10 and 11 for the desired shock pressure. Figures 12 and 13 indicate the time required for pressurization and heating. The facility is operated in conformance with a Standing Operating Procedure, an appendix of which is a check list that is used in preparation for all shots.

The fastest operating rate for two-tube operation is one shot every two days for weak shocks and every three days for strong shocks. This is primarily due to the long pumping times required to attain the required driver pressure, and also because this time is doubled due to the necessity for pressurizing to prebulge the diaphragm before application of the cutting charge. It takes two men five hours to remove the two spent diaphragms and install two new ones. Installing and arming the two cutting charges takes one hour. In addition to these time requirements, there is usually an overnight delay for cooling the driver section of the 5 1/2 foot

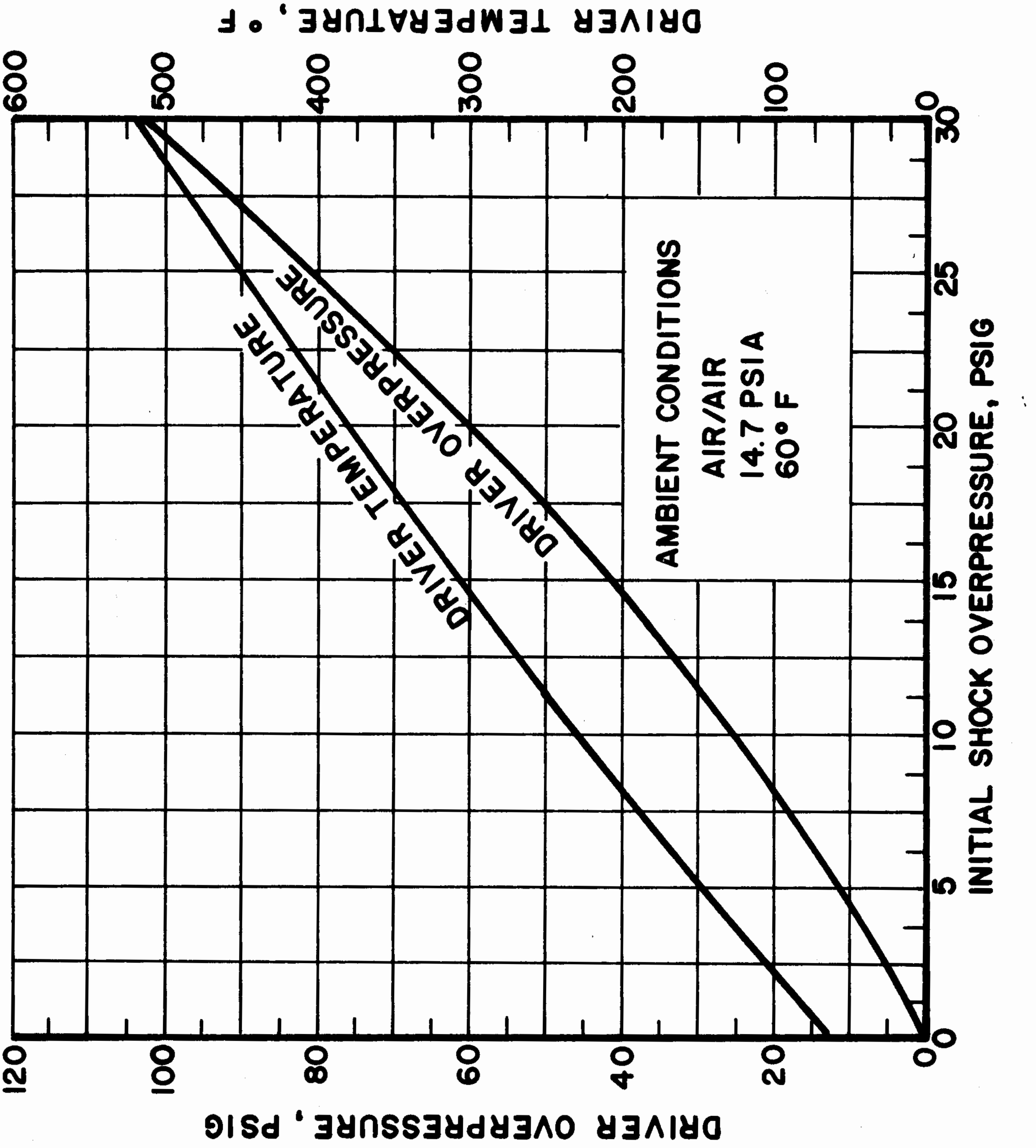


Figure 10. Shock Pressure vs. Driver Conditions, Small Tube

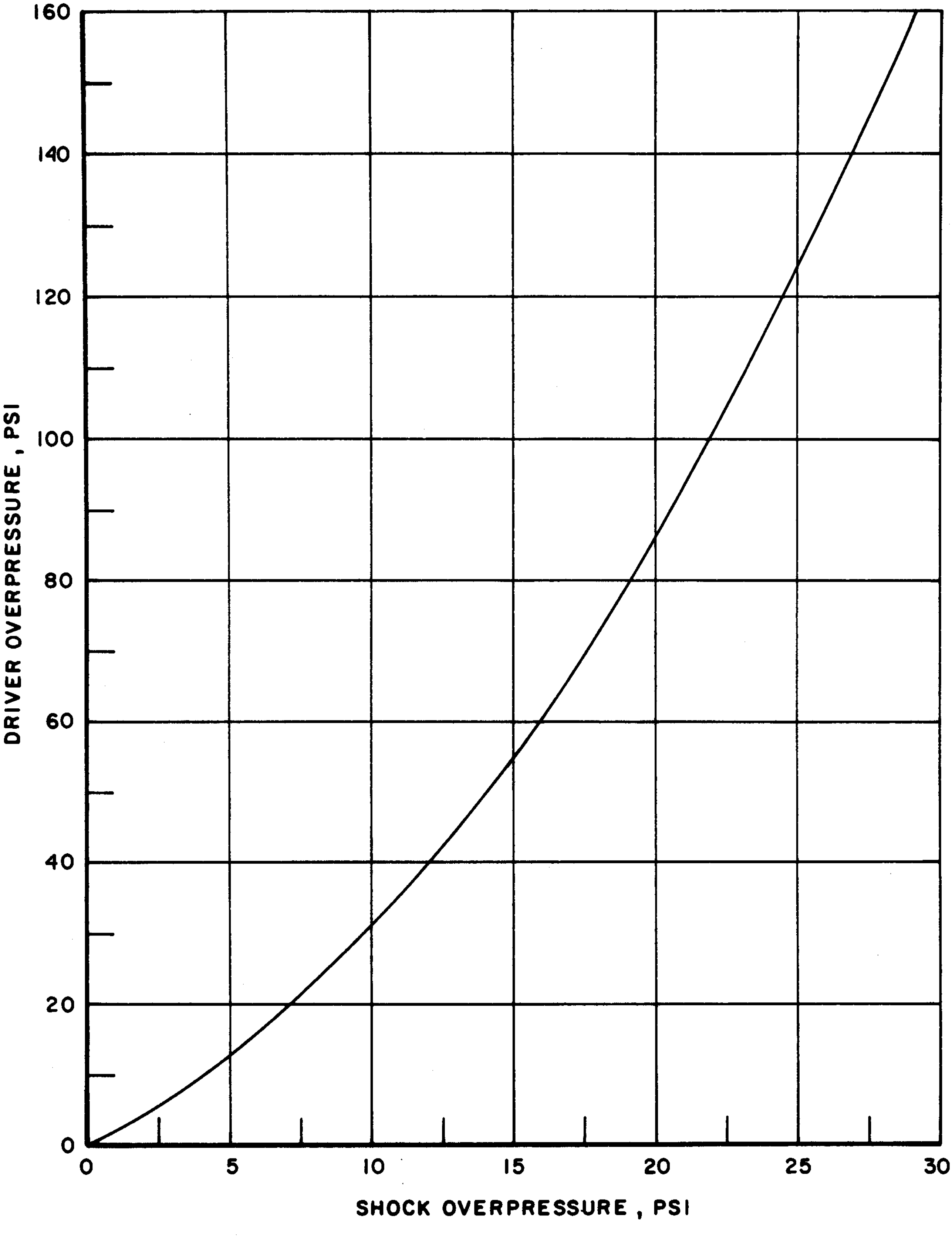


Figure 11. Shock Pressure vs. Driver Pressure, Large Tube

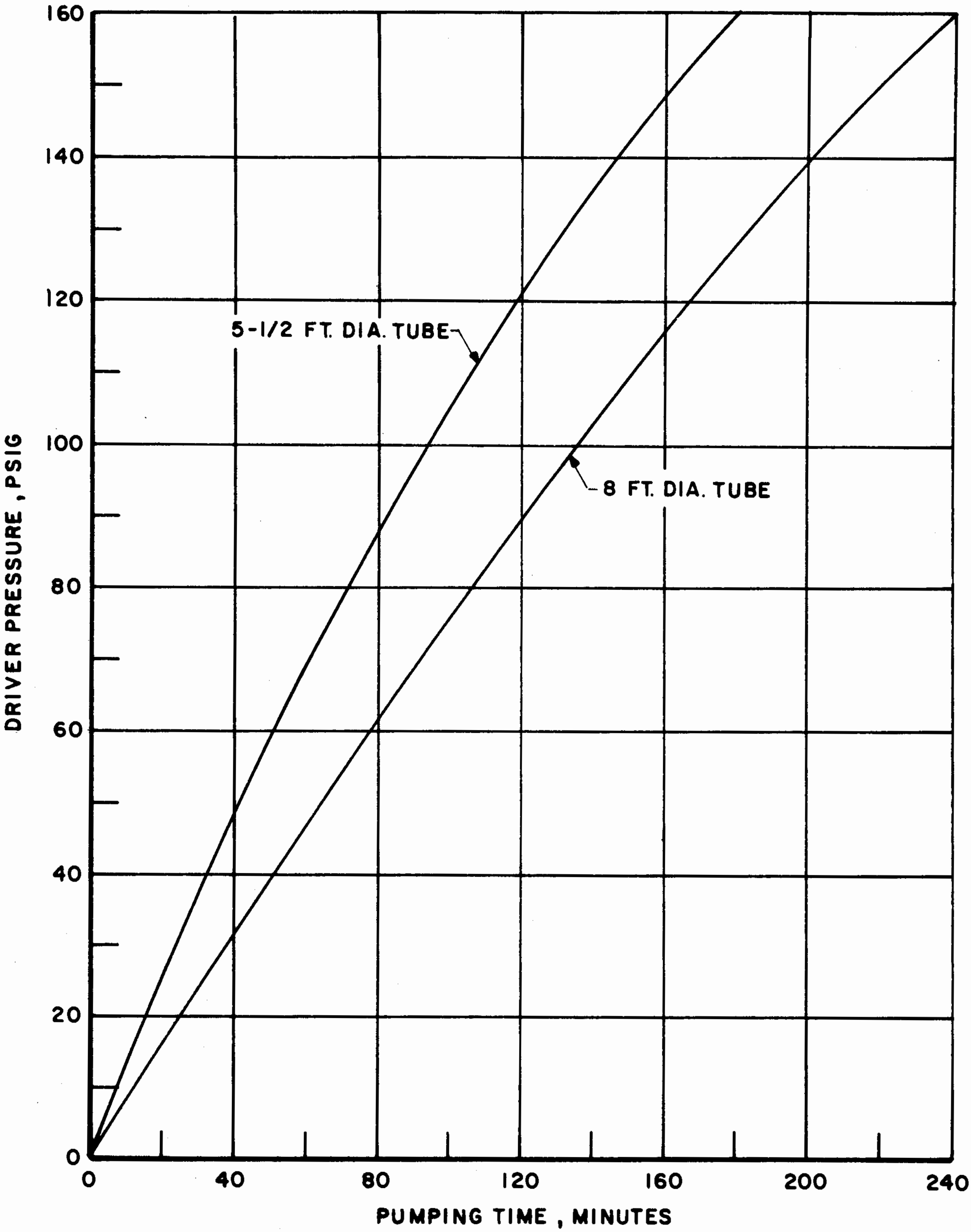


Figure 12. Driver Pressure vs Pumping Time

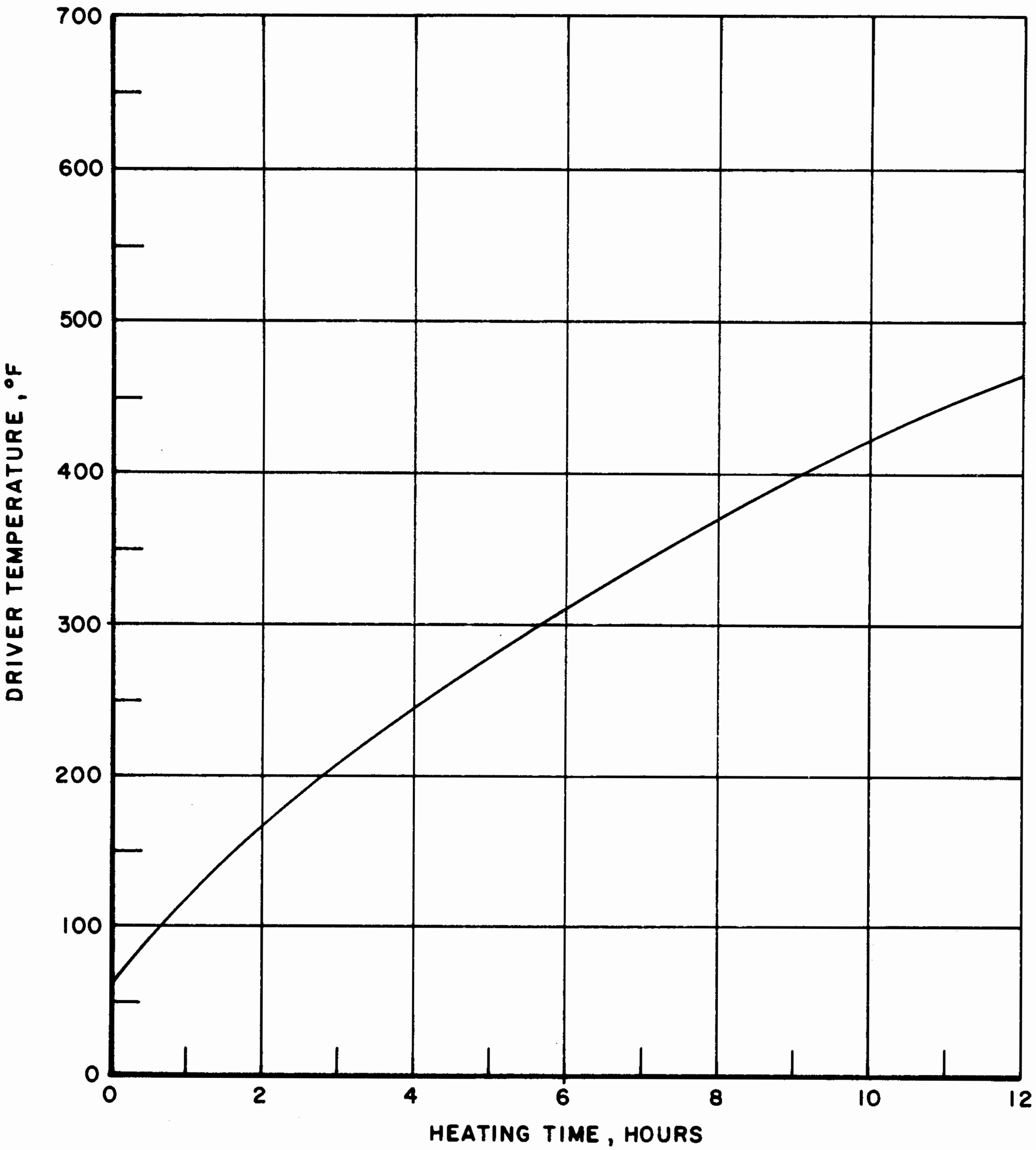


Figure 13. Driver Temperature vs. Heating Time, Small Shock Tube

diameter tube so the driver section can be entered to inspect it for possible small diaphragm fragments that might damage a test item during the next shot.

There are other limitations that presently apply to the operation of the facility. The tube exits are close to the shoreline of the Chesapeake Bay, so patrol boats are required during pumping operations to keep other water traffic clear of the area. Also, since the Laboratories desire to maintain their good community relations, it has been the custom to curtail operation after Four PM so that sport fishing and other boating can be permitted in the area. For this same reason, there is no firing at the facility on weekends.

IV. RESULTS

A. Diaphragms

The area of greatest concern has been diaphragm operation, but the diaphragms have proved to be reasonably trouble free. There was one instance when a diaphragm pulled in during pre-bulge on the large tube because a retaining ring weld failed.

There is a tendency for the diaphragm petals to tear along their root, or bend line, especially in the case of the thicker diaphragms (10 gage). This occurs because the petal must bend over the curved inner perimeter of the downstream flange, in effect bending on a concave hinge line. Although no petals have torn completely out this is still an area of concern, so plans are being considered to weld eight straight sections in the perimeter of the downstream flange along which the petals can bend. The modification would result in an area change in the diaphragm region of about 5%.

The tips of the diaphragm petals wrap around the catcher bars in the tube wall as desired (Figure 9), occasionally a tip shears off

but is retained in the pocket beneath the catcher bar. When a tip does shear off, the petal sometimes either rebounds or is picked up and flexes in the flow reversals following the shock wave. The tip catchers are being modified to improve their operation.

There is no significant difference in diaphragm operation resulting from the cutting charge being applied to the downstream instead of the upstream face. The core-load of the linear shaped charges must be sufficient to completely sever the steel diaphragm if the diaphragm tips are to engage the catcher bars accurately. Table 1 shows core loads used for various diaphragm thicknesses.

B. Shock Waves

1. Small Shock Tube. The shock pressure records obtained from this tube are very close to predictions, both in pressure level and duration, with the engine inlet junction closed. The boundary layer does cause a gradual pressure increase between the shock front and the rarefaction wave as is typical in shock tubes. The stagnation pressure records show no sign of pressure increase at the interface so the interface is successfully matched by heating the driver air. With the engine ducting in place there are small cyclic pressure changes in the shock tube (rarefaction and compression waves) resulting from the shock entering the duct and reflecting at the engine.

2. Large Shock Tube. Shock pressure records obtained from this tube are also close to predicted values, when the tube is operated with the exhaust duct junction closed. The cold air interface is evident in the stagnation pressure records. The performance of this tube is modified when an engine is attached and operating principally due to the hot exhaust gases that fill the driven section, but also because of the open duct junction. The effect of the hot exhaust gas is

to produce an energy ratio across the diaphragm in a direction that results in weaker shock formation. The distribution of exhaust gas temperature and flow is complicated so it is difficult to predict accurately the effects of the exhaust gas on shock pressure. This problem was solved by firing a weak shock on the engine, entering the measured shock pressure versus driver pressure in the shock tube equation and calculating the effective energy ratio. This was used to produce a new curve of shock pressure versus driver pressure for that particular engine's exhaust products. Figure 14 shows idealized pressure histories in both tubes. The original pressure records are all too long to reproduce for this report.

V. CONCLUSION

The Dual Shock Tube Facility has been operated successfully on the task for which it was designed. It will continue to be used for engine testing in the near future, but its size and capabilities make it a fine candidate for other testing that requires large test sections and well-controlled shock waves.

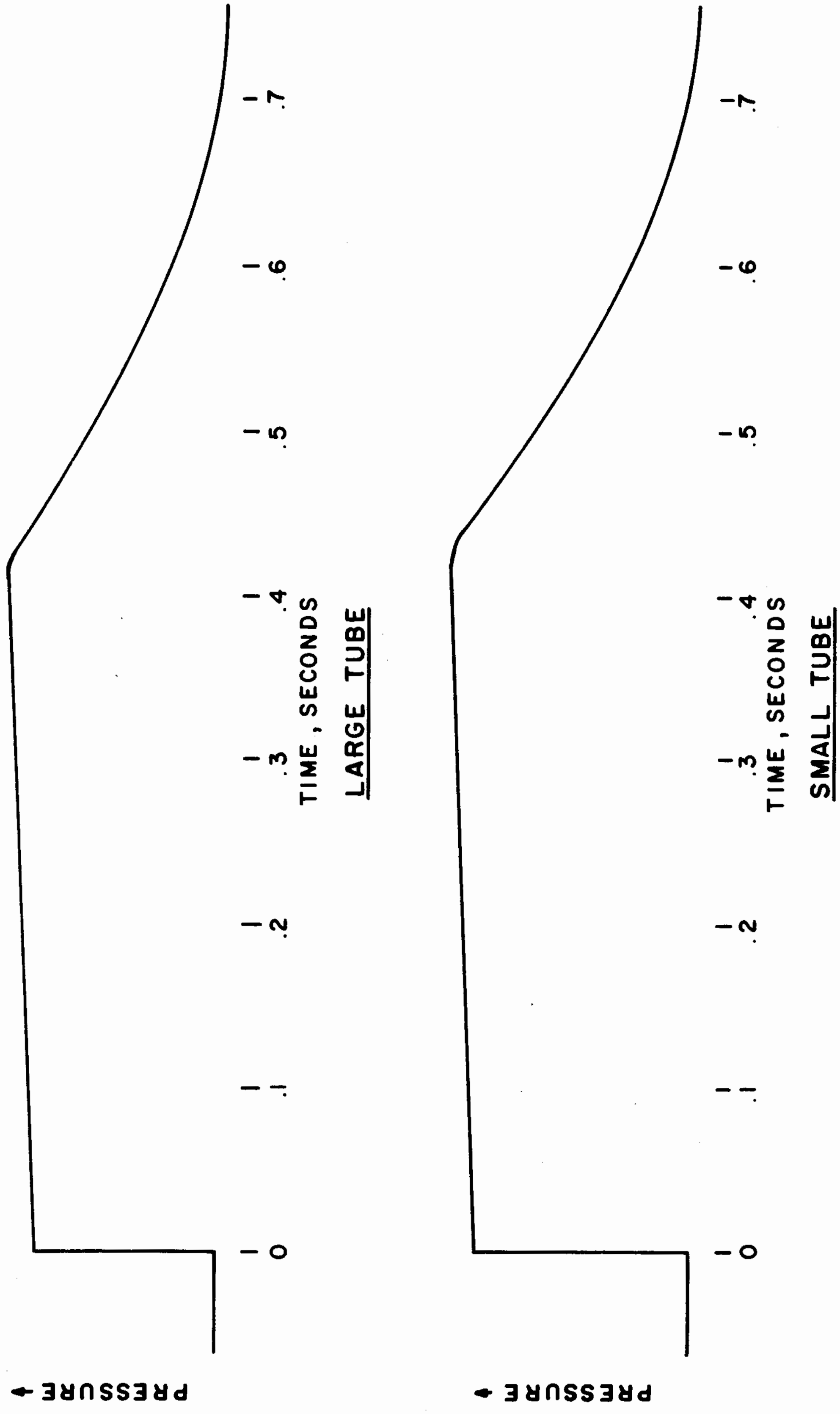


Figure 14. Idealized Pressure History in Shock Tubes

ACKNOWLEDGEMENT

The Dual Shock Tube Facility was brought into successful operation very soon after its construction in order to conform with a tight schedule. The completion of the first phase of this high priority testing and the Facility's present dependable operation are due principally to the skill and cooperation of Warren Baity, Kenneth Holbrook, and Robert Peterson.

DISTRIBUTION LIST

No. of Copies	Organization
20	Commander Defense Documentation Center ATTN: TIPCR Cameron Station Alexandria, Virginia 22314
1	Director of Defense Research and Engineering (OSD) ATTN: Dir/Tech Info Washington, D.C. 20301
1	Director Institute for Defense Analyses ATTN: Mr. F. Prozel 400 Army-Navy Drive Arlington, Virginia 22202
2	Headquarters Defense Atomic Support Agency Washington, D.C. 20305
4	Chief, Test Command Defense Atomic Support Agency ATTN: TCTB-B Sandia Base Albuquerque, New Mexico 87115
1	Commanding General U.S. Army Materiel Command ATTN: AMCRD-TE Washington, D.C. 20315
1	Commanding General U.S. Army Materiel Command ATTN: AMCRD-TP Washington, D.C. 20315
1	Commanding General U.S. Army Materiel Command ATTN: AMCRD-BC Washington, D.C. 20315
2	Commanding General U.S. Army Materiel Command ATTN: AMCRD-BN Washington, D.C. 20315

No. of Copies	Organization
1	Commanding Officer U.S. Army Mobility Equipment Research & Development Center ATTN: Tech Docu Cen, Bldg 315 Fort Belvoir, Virginia 22060
1	President U.S. Army Air Defense Board Fort Bliss, Texas 79916
1	Commanding General U.S. Army White Sands Missile Range New Mexico 88002
1	Commanding Officer U.S. Army Combat Developments Command Institute of Nuclear Studies Fort Bliss, Texas 79916
1	Director of Civil Defense ATTN: Mr. N. Landdeck Department of the Army Washington, D.C. 20310
2	Commanding Officer U.S. Army Engineer Waterways Experiment Station ATTN: Lib Nuclear Wpns Effects Br P.O. Box 631 Vicksburg, Mississippi 39180
3	Chief of Engineers ATTN: ENGMC-D ENGMC-EM ENGTE-E Department of the Army Washington, D.C. 20315
1	Chief of Research & Development ATTN: CRDCM Department of the Army Washington, D.C. 20310

DISTRIBUTION LIST

No. of Copies	Organization
1	Commandant U.S. Army Command and General Staff College ATTN: Archives Fort Leavenworth, Kansas 66027
1	Chief Joint Civil Defense Support Group Chief of Engineers Department of the Army Gravelly Point Washington, D.C. 20310
3	Commander U.S. Naval Air Systems Command ATTN: AIR-604 Washington, D.C. 20360
3	Commander U.S. Naval Ordnance Systems Command ATTN: ORD-9132 Washington, D.C. 20360
1	Commander U.S. Naval Facilities Engineering Command Washington, D.C. 20360
1	Commanding Officer & Director U.S. Naval Civil Engineering Laboratory ATTN: Code L31 Port Hueneme, California 93041
1	Commander U.S. Naval Ordnance Laboratory Silver Spring, Maryland 20919
1	Superintendent U.S. Naval Postgraduate School ATTN: Tech Repts Sec Monterey, California 93940

No. of Copies	Organization
1	Commanding Officer & Director U.S. Naval Ship Research and Development Center ATTN: Code 042, Lib Washington, D.C. 20007
3	HQ USAF (AFRDC, AFNIN, AFOCE) Washington, D.C. 20330
3	AFWL (WLRE, WLRC, WLDC, Mr. Clark) Kirtland AFB New Mexico 87117
1	Director U.S. Bureau of Mines Eastern Experiment Station College Park, Maryland 20740
1	Headquarters U.S. Atomic Energy Commission ATTN: Div of Tech Info Mrs. J. O'Leary Washington, D.C. 20545
2	Director Lawrence Radiation Laboratory ATTN: Tech Info Div Mrs. B. Crowley Livermore, California 94550
1	Director Los Alamos Scientific Laboratory ATTN: Rept Lib P.O. Box 1663 Los Alamos, New Mexico 87544
2	Arthur D. Little, Co. ATTN: D. S. Allen Acorn Park Cambridge, Massachusetts 02140
1	General American Transportation Corporation MRD Division 7449 N. Natchez Avenue Niles, Illinois 60648

DISTRIBUTION LIST

No. of Copies	Organization
1	Advisory Committee on Civil Defense National Academy of Sciences ATTN: Mr. R. Park 2101 Constitution Avenue Washington, D.C. 20418
1	The Rand Corporation ATTN: Dr. H. Brode 1700 Main Street Santa Monico, California 90406
1	Sandia Corporation ATTN: Info Distr Div Mr. L. Vortman P.O. Box 5800 Albuquerque, New Mexico 87115
1	United Research Services 1811 Trousdale Drive Burlingame, California 94011
1	IIT Research Institute 10 West 35th Street ATTN: Dr. E. Sevin Chicago, Illinois 60616
2	University of Illinois Talbot Laboratory ATTN: Dr. N. Newmark Dr. W. Hall Urbana, Illinois 61803
1	Stanford Research Institute ATTN: Mr. J. Halsey Civil Defense Technical Office Menlo Park, California 94025

Aberdeen Proving Ground

Ch, Tech Lib
Marine Corps Ln Ofc
Navy Ln Ofc
CDC Ln Ofc